Computational Modeling of Thermophysical Properties of Silica Reinforced Porous Anodized Aluminum (SiRPA) Based Thermal Swing Coating

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Abstract

In this research, a 3-dimensional finite element model of Silica Reinforced Porous Anodized Aluminum (SiRPA) based Thermal Swing Coating is developed to predict its thermophysical properties and compare with properties obtained by physical testing. The computational model of SiRPA is developed based on the morphology of an experimentally grown coating structure and known relationship of geometry and anodization parameters. A steady state thermal Finite Element Analysis is then conducted to calculate the thermophysical properties. Predicted thermal conductivity, thermal diffusivity and bulk density are 0.67 W/mK, 0.46 mm^2/s and 1504 kg/m^3 respectively, compared to experimentally obtained 0.67 W/mK, 0.52 mm^2/s and 1400 kg/m^3. A transient thermal analysis is also conducted to verify the 'Temperature Swing' effect of the coating by comparing the temperature fluctuation of SiRPA coating with traditional Yttria Stabilized Zirconia (YSZ) based thermal barrier coating (TBCs). Based on average of 20 cycles, SiRPA coating is observed to show 53% higher fluctuation compared to YSZ based TBCs.

1. Introduction

Thermal Barrier Coatings (TBCs) have been employed on high temperature components of Internal Combustion (IC) engines such as piston head, exhaust manifold and gas turbine components like nickel-based superalloy turbine blades. TBCs because of its low thermal conductivity and high heat capacity aids to reduce the substrate temperature and thereby improves the thermal durability of the components. Also, there occurs high surface temperatures on the insulating top coat of TBCs. In case of IC engines, the TBCs raises combustion wall temperatures and reduces the temperature difference in working gas and wall surfaces. TBCs thus insulates the heat flow from in-cylinder working gas to combustion wall and thereby reduces the heat lost from the combustion chamber. In IC engines, reduction in heat losses is a key factor in improving thermal efficiency. In addition, this increased thermal energy can be recovered from turbochargers, thereby improving the efficiency.

Several investigations have been conducted on IC engine pistons coated with traditional ceramic based TBCs to evaluate the heat loss reduction and gain in thermal efficiency of the engine. However, traditional ceramic based TBCs have shown invariably high surface temperatures both during the intake and compression strokes because of its high heat capacity. As a result, during the intake stroke the incoming air was preheated which shortened the ignition delay, increased the viscosity of the in-cylinder gas and deteriorated the air-fuel mixture. This led to an increase in